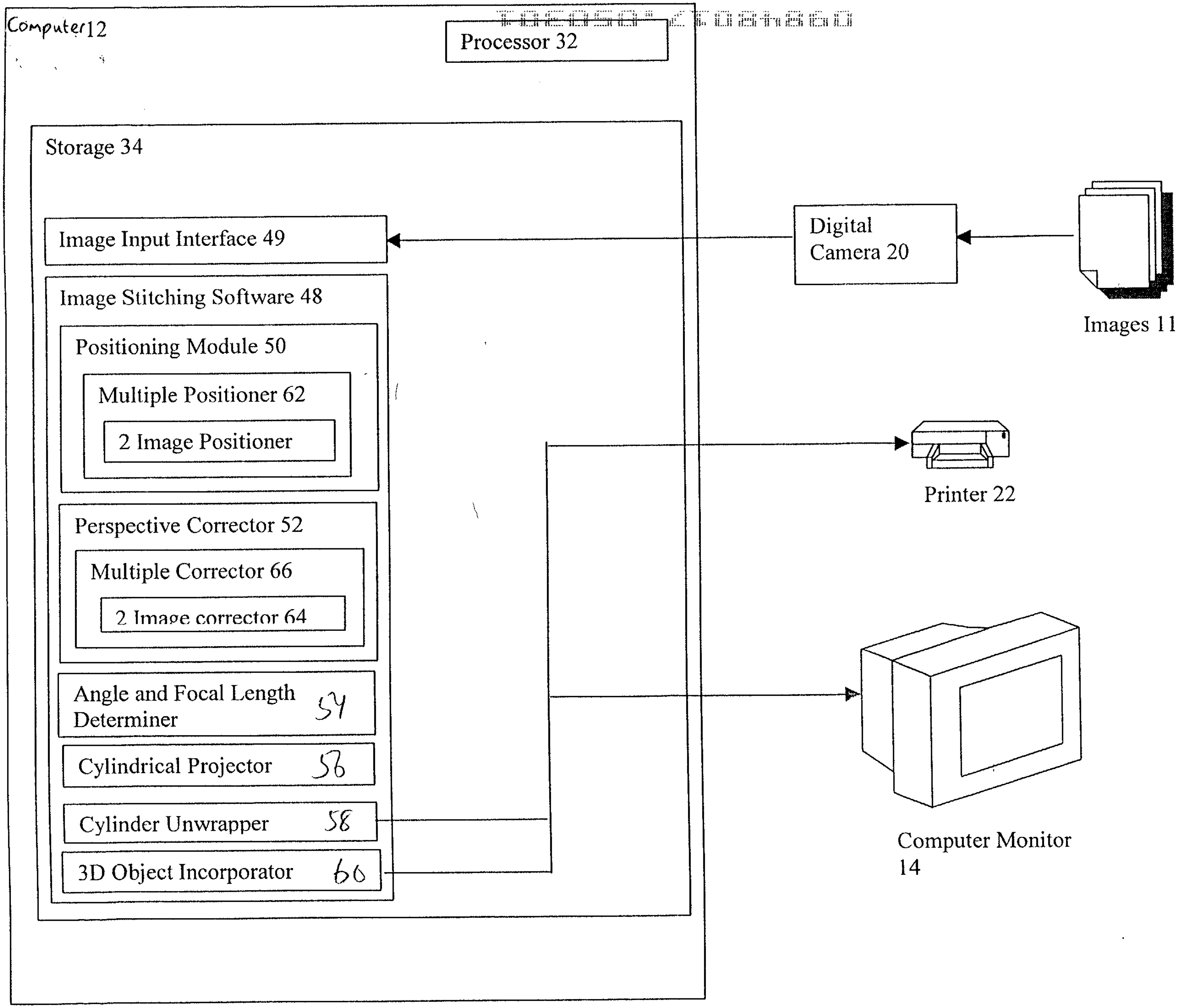
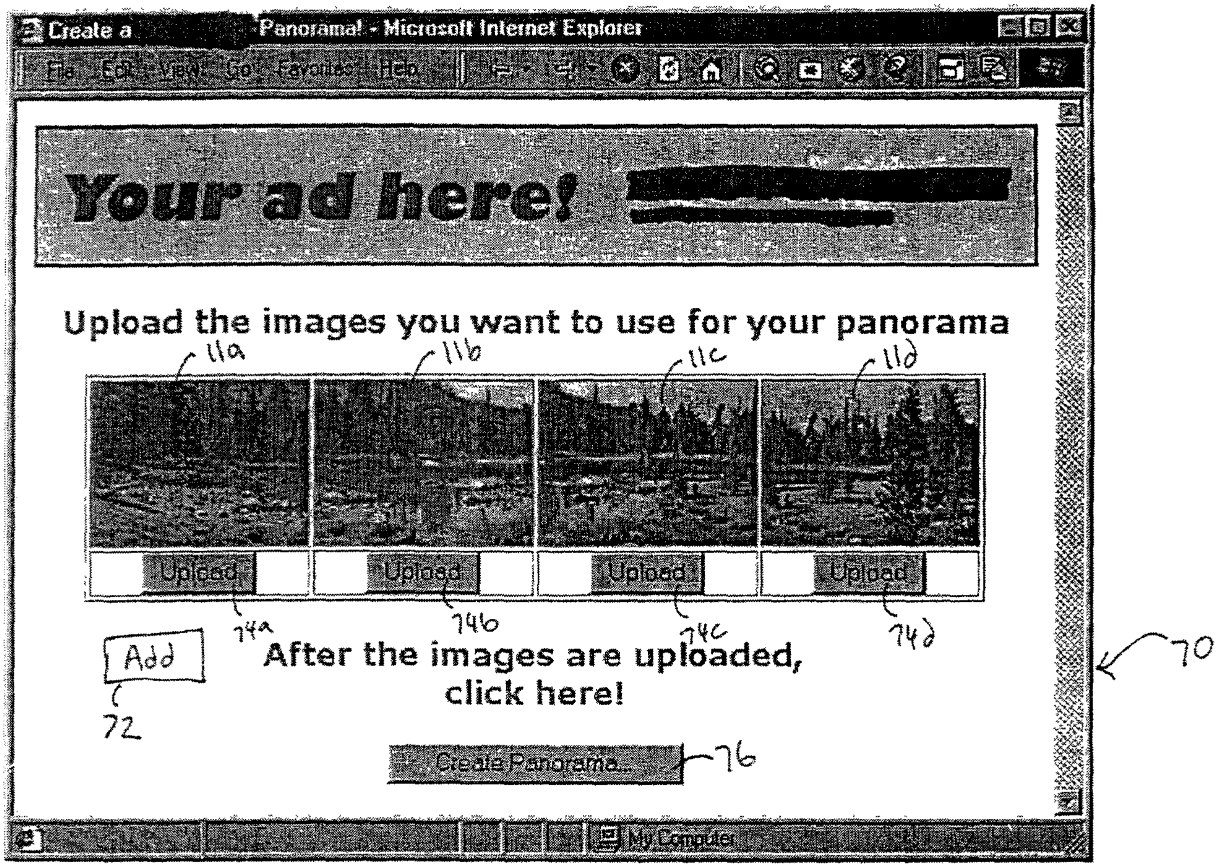
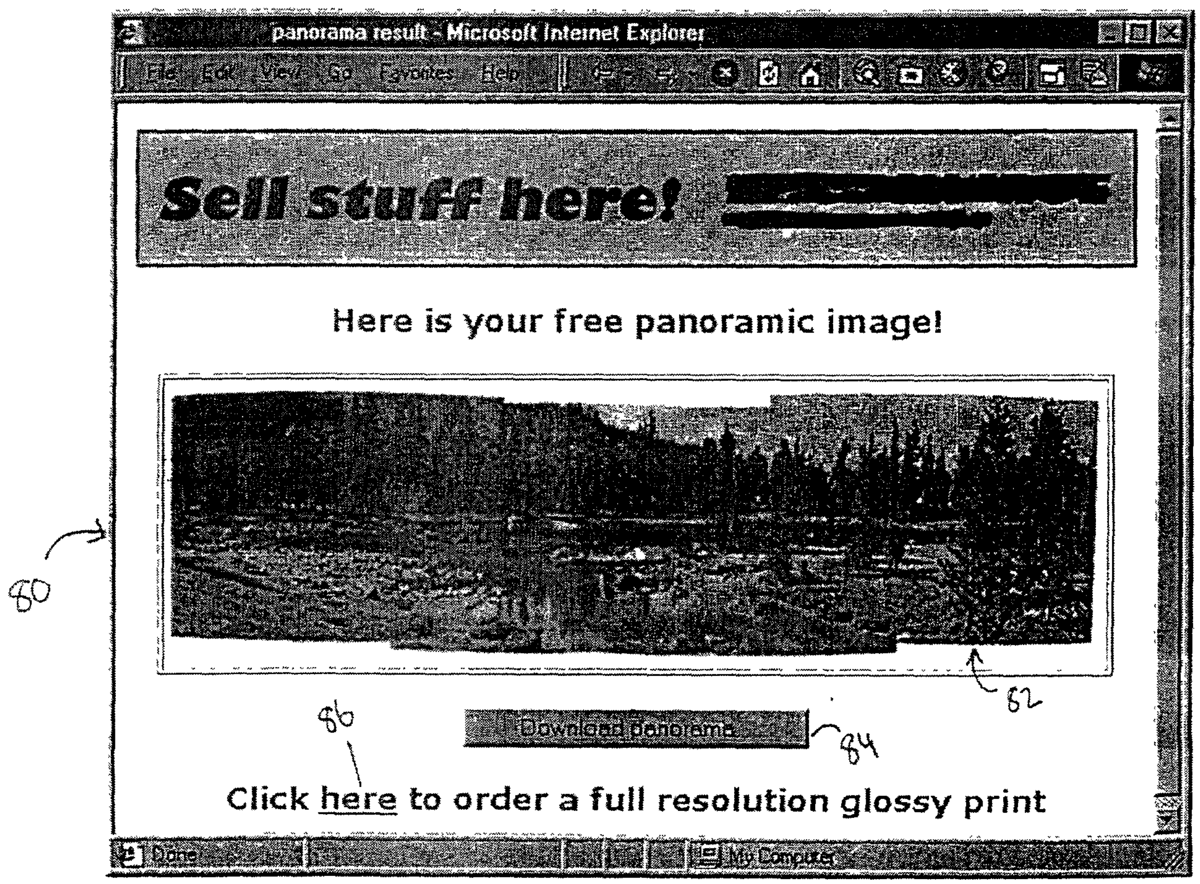

Computer12
Processor 32
Storage 34
Image Input Interface 49
Image Stitching Software 48
Positioning Module 50
Multiple Positioner 62
2 Image Positioner
Perspective Corrector 52
Multiple Corrector 66
2 Image corrector 64
Angle and Focal Length Determiner 54
Cylindrical Projector 56
Cylinder Unwrapper 58
3D Object Incorporator 60
Digital Camera 20
Images 11
Printer 22
Computer Monitor 14

Fig. 1



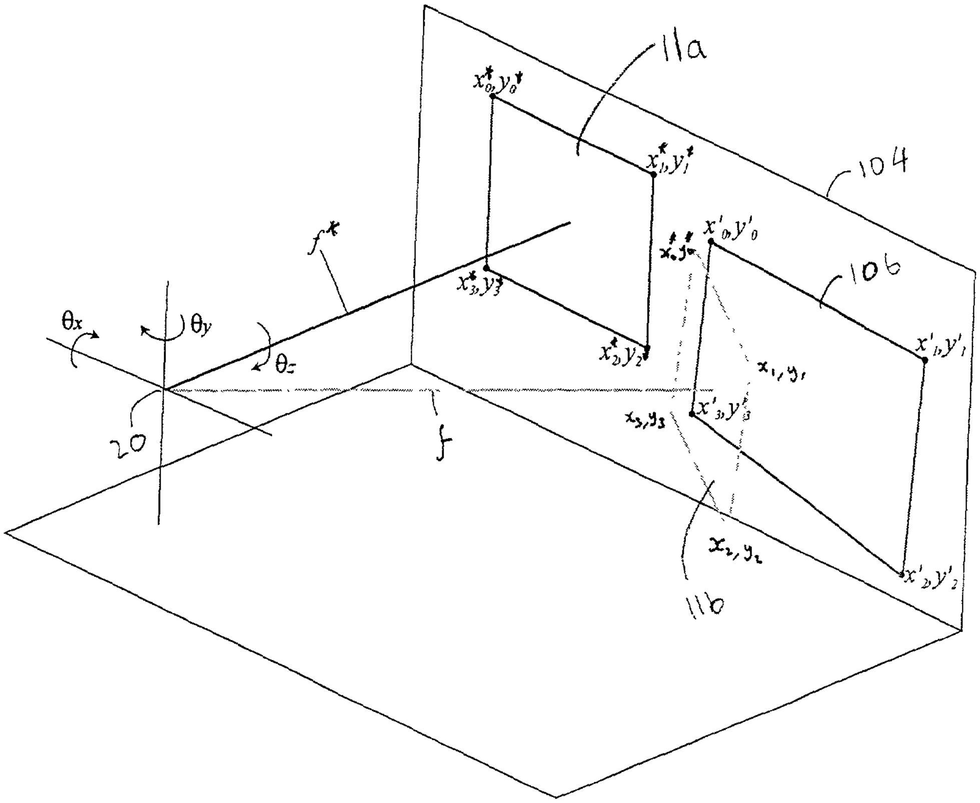
Create a [redacted] Panorama! - Microsoft Internet Explorer
File Edit View Go Favorites Help
Your ad here! [redacted]
Upload the images you want to use for your panorama
11a
11b
11c
11d
Upload
Upload
Upload
Upload
74a
74b
74c
74d
Add
72
After the images are uploaded,
click here!
Create Panorama...
76
70
My Computer

Fig. 2A



panorama result - Microsoft Internet Explorer
File Edit View Go Favorites Help
Sell stuff here! [redacted]
Here is your free panoramic image!
80
82
86
Download panorama...
84
Click here to order a full resolution glossy print
Done
My Computer

Fig. 2B



11a
x_0^*, y_0^*
x_1^*, y_1^*
104
f^*
x'_0, y'_0
x_0^*, y_0^*
106
x_3^*, y_3^*
θx
θy
θz
x_2^*, y_2^*
x'_1, y'_1
x_1, y_1
x_3, y_3
x'_3, y'_3
20
f
x_2, y_2
x'_2, y'_2
116

Fig. 3

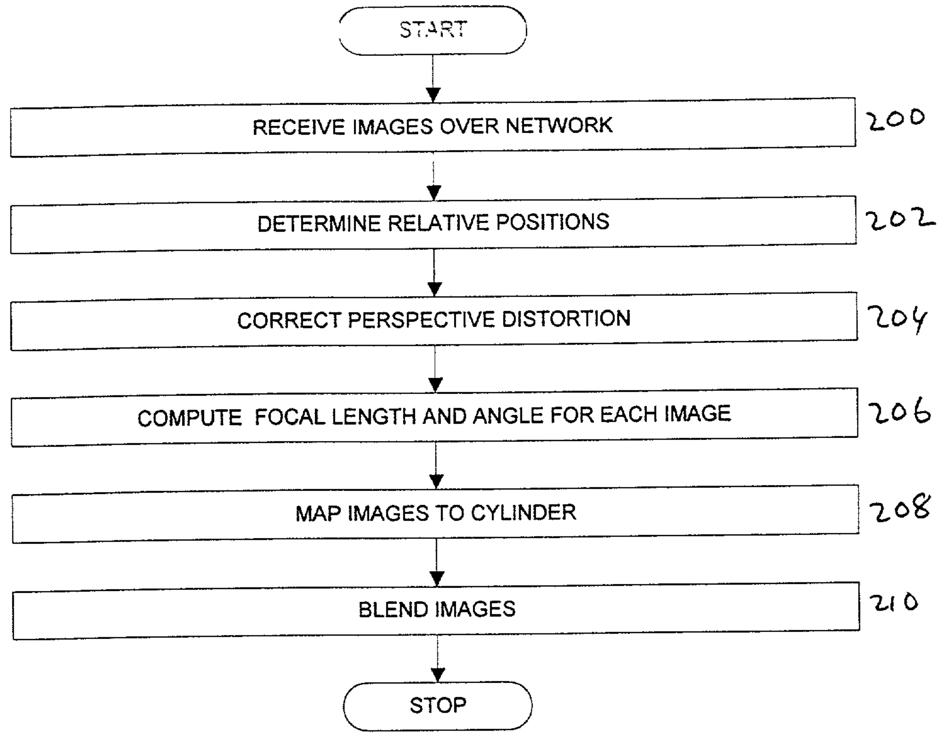

START
RECEIVE IMAGES OVER NETWORK
200
DETERMINE RELATIVE POSITIONS
202
CORRECT PERSPECTIVE DISTORTION
204
COMPUTE FOCAL LENGTH AND ANGLE FOR EACH IMAGE
206
MAP IMAGES TO CYLINDER
208
BLEND IMAGES
210
STOP

Fig. 4

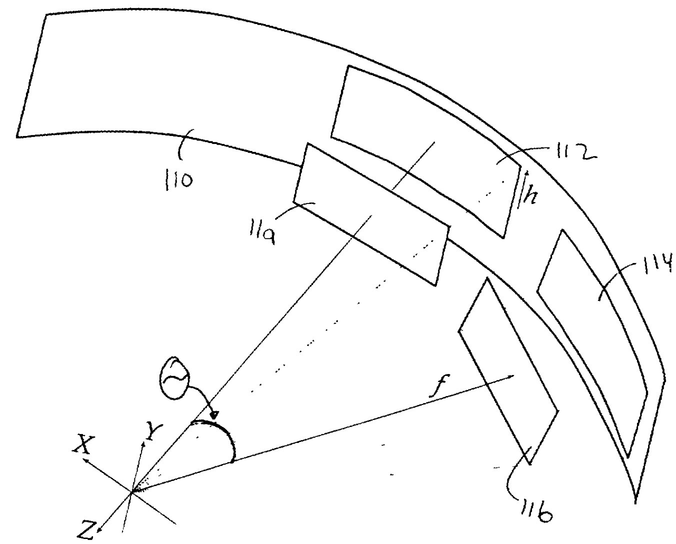


Fig. 5A

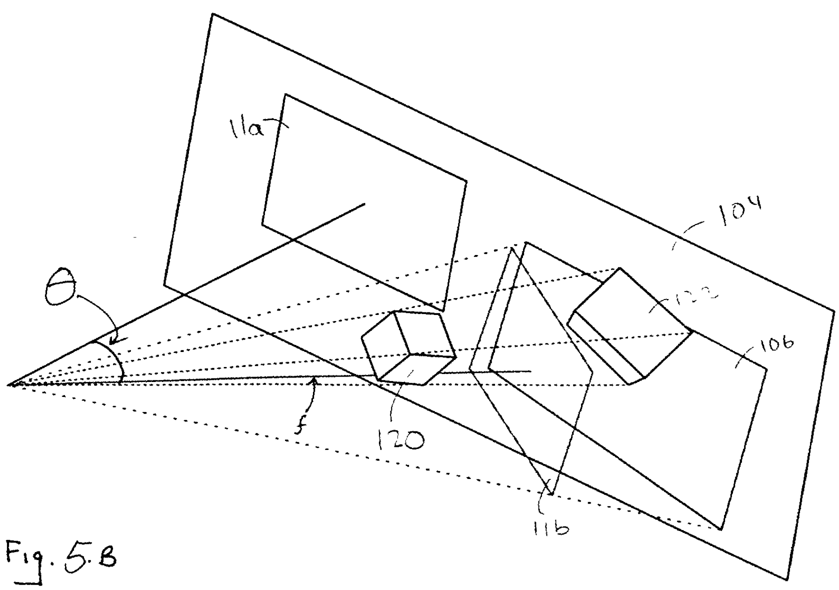


Fig. 5B

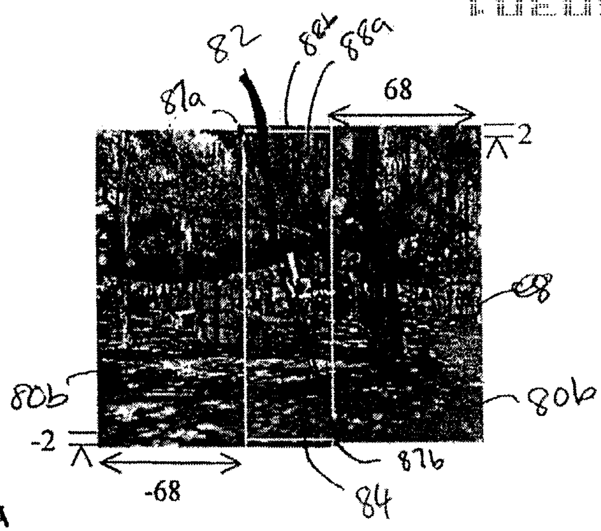


FIG. 6A

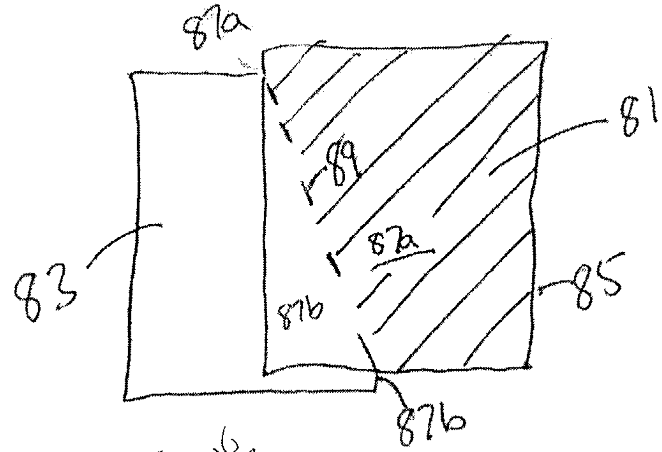


FIG. 6F

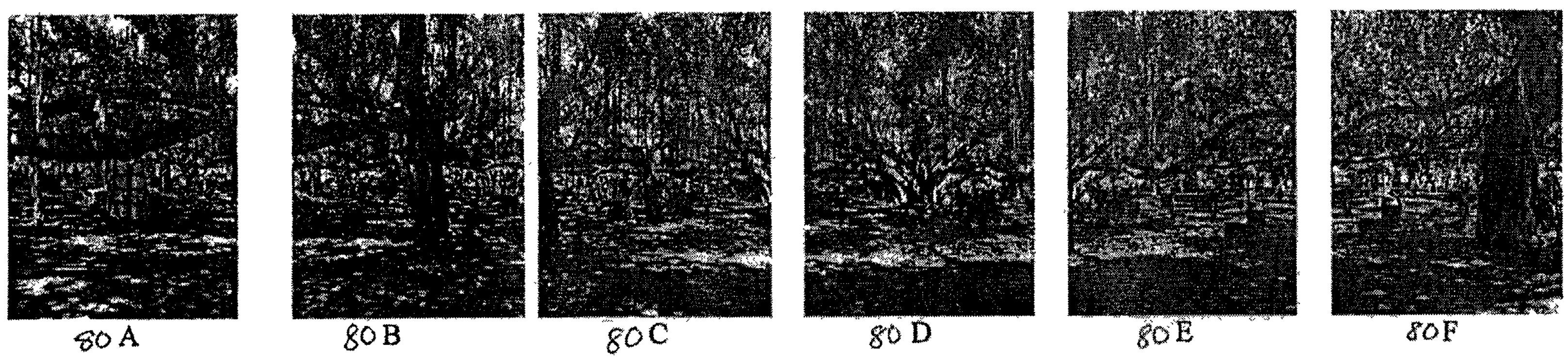


FIG. 6B

Adjacent Lists

86A	86B	86C	86D	86E	86F
B: 68, 2	A: -68, -2 C: 69, 4	B: -69, -4 D: 66, -1	C: -66, -1 E: 66, -1	D: -66, 1 E: 67, -2	E -67,2

Fig. 6C

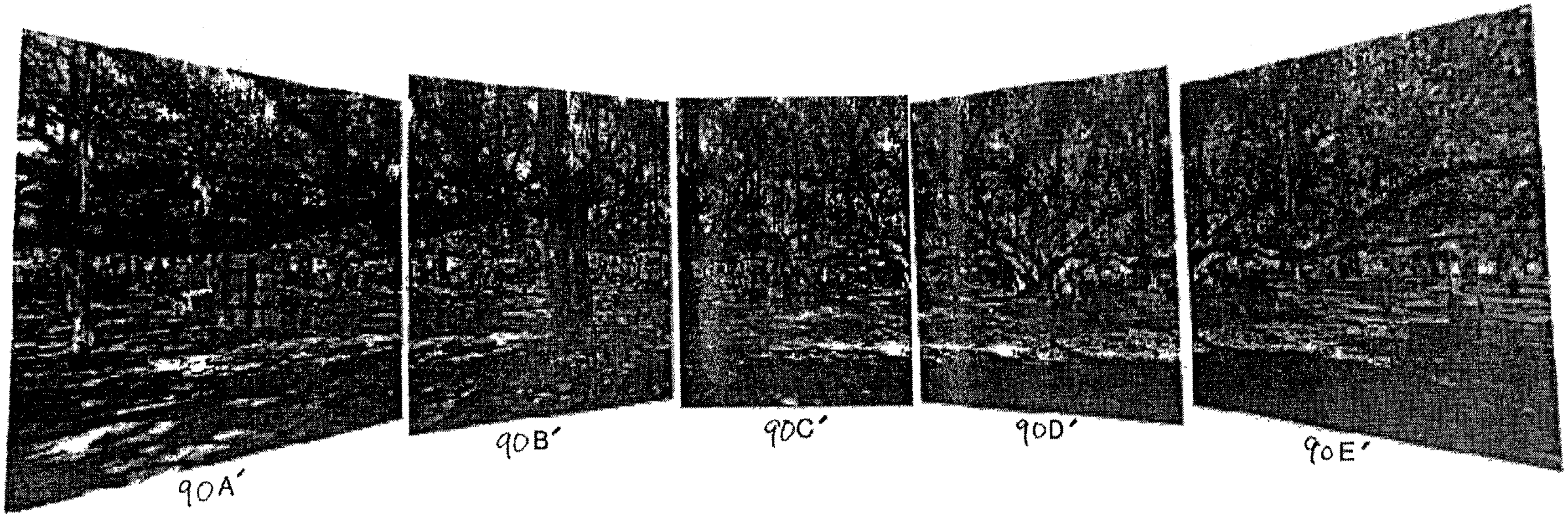


FIG. 6D

Select C as "base"
Align B, D to C
Align A to B and E to D

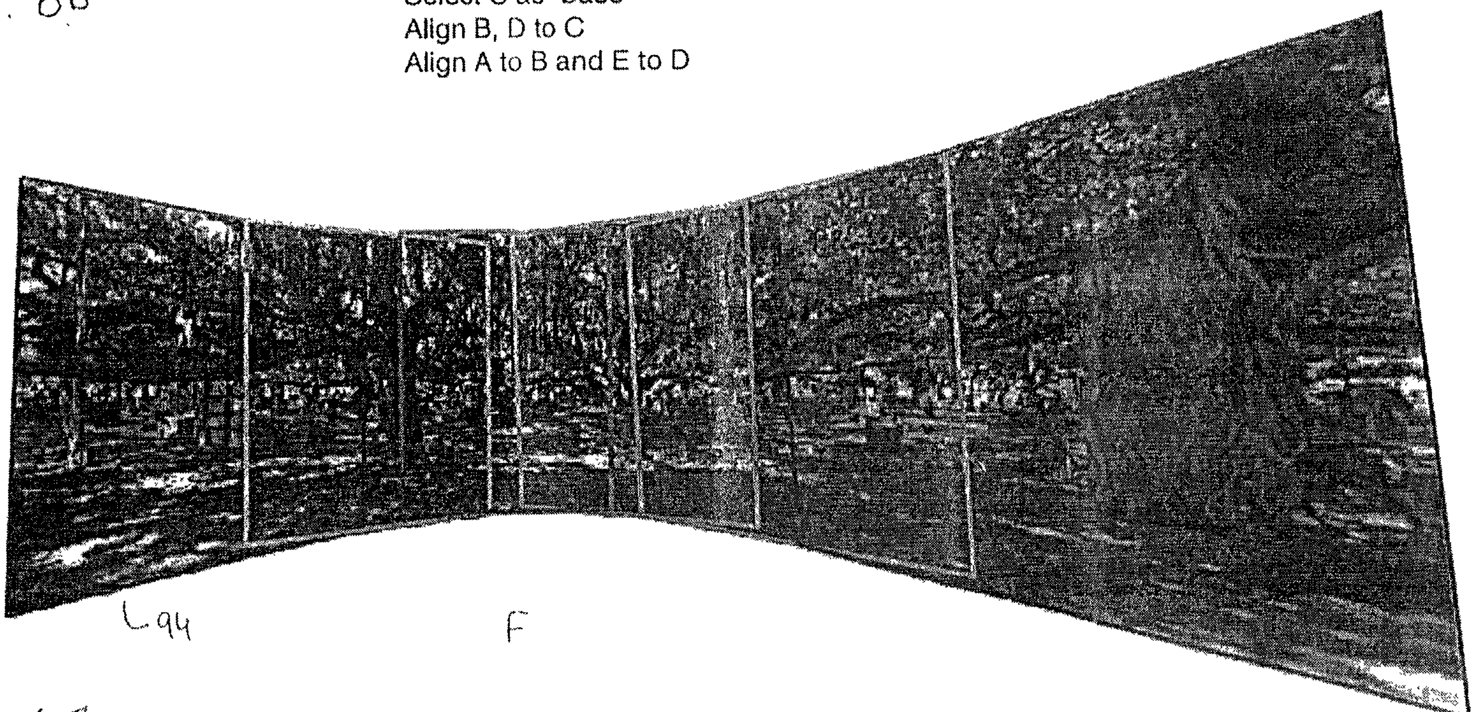


FIG. 6E

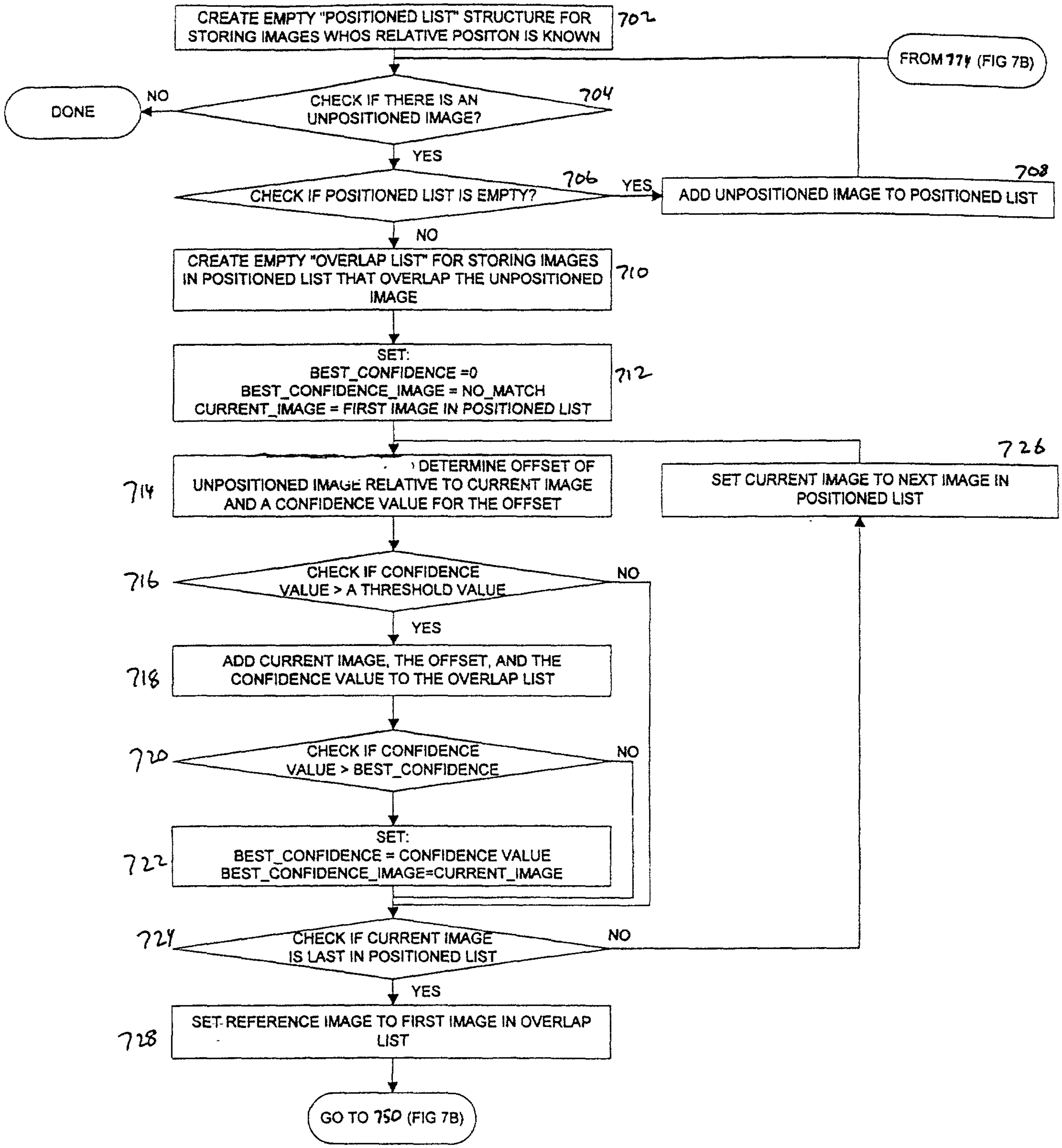

CREATE EMPTY "POSITIONED LIST" STRUCTURE FOR STORING IMAGES WHOS RELATIVE POSITON IS KNOWN
702
FROM 774 (FIG 7B)
DONE
NO
CHECK IF THERE IS AN UNPOSITIONED IMAGE?
704
YES
CHECK IF POSITIONED LIST IS EMPTY?
706
YES
ADD UNPOSITIONED IMAGE TO POSITIONED LIST
708
NO
CREATE EMPTY "OVERLAP LIST" FOR STORING IMAGES IN POSITIONED LIST THAT OVERLAP THE UNPOSITIONED IMAGE
710
SET:
BEST_CONFIDENCE =0
BEST_CONFIDENCE_IMAGE = NO_MATCH
CURRENT_IMAGE = FIRST IMAGE IN POSITIONED LIST
712
726
SET CURRENT IMAGE TO NEXT IMAGE IN POSITIONED LIST
714
DETERMINE OFFSET OF UNPOSITIONED IMAGE RELATIVE TO CURRENT IMAGE AND A CONFIDENCE VALUE FOR THE OFFSET
716
CHECK IF CONFIDENCE VALUE > A THRESHOLD VALUE
NO
YES
718
ADD CURRENT IMAGE, THE OFFSET, AND THE CONFIDENCE VALUE TO THE OVERLAP LIST
720
CHECK IF CONFIDENCE VALUE > BEST_CONFIDENCE
NO
722
SET:
BEST_CONFIDENCE = CONFIDENCE VALUE
BEST_CONFIDENCE_IMAGE=CURRENT_IMAGE
724
CHECK IF CURRENT IMAGE IS LAST IN POSITIONED LIST
NO
YES
728
SET REFERENCE IMAGE TO FIRST IMAGE IN OVERLAP LIST
GO TO 750 (FIG 7B)

Fig. 7A

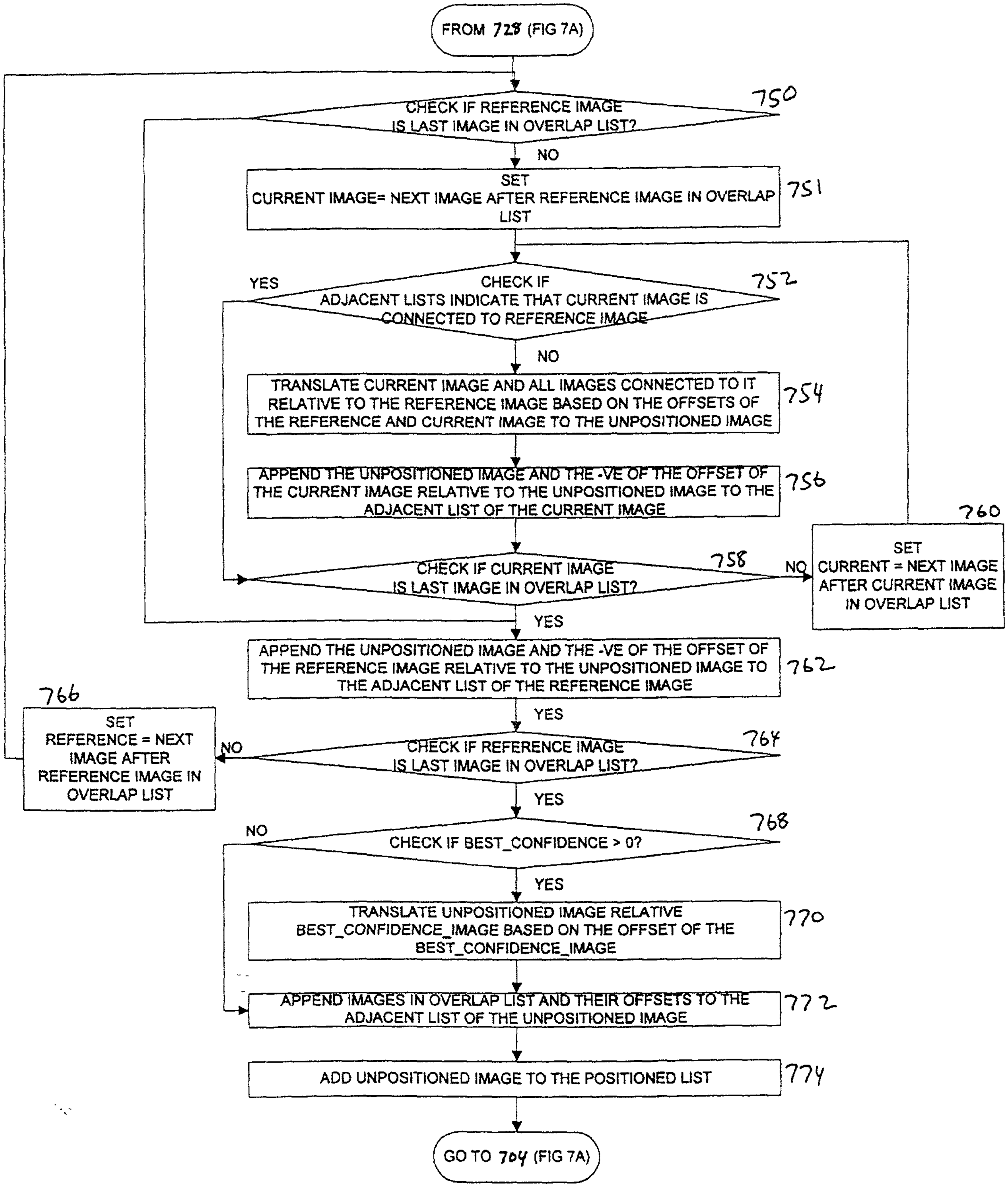

FROM 728 (FIG 7A)
CHECK IF REFERENCE IMAGE IS LAST IMAGE IN OVERLAP LIST?
750
NO
SET CURRENT IMAGE= NEXT IMAGE AFTER REFERENCE IMAGE IN OVERLAP LIST
751
YES
CHECK IF ADJACENT LISTS INDICATE THAT CURRENT IMAGE IS CONNECTED TO REFERENCE IMAGE
752
NO
TRANSLATE CURRENT IMAGE AND ALL IMAGES CONNECTED TO IT RELATIVE TO THE REFERENCE IMAGE BASED ON THE OFFSETS OF THE REFERENCE AND CURRENT IMAGE TO THE UNPOSITIONED IMAGE
754
APPEND THE UNPOSITIONED IMAGE AND THE -VE OF THE OFFSET OF THE CURRENT IMAGE RELATIVE TO THE UNPOSITIONED IMAGE TO THE ADJACENT LIST OF THE CURRENT IMAGE
756
760
SET CURRENT = NEXT IMAGE AFTER CURRENT IMAGE IN OVERLAP LIST
CHECK IF CURRENT IMAGE IS LAST IMAGE IN OVERLAP LIST?
758
NO
YES
APPEND THE UNPOSITIONED IMAGE AND THE -VE OF THE OFFSET OF THE REFERENCE IMAGE RELATIVE TO THE UNPOSITIONED IMAGE TO THE ADJACENT LIST OF THE REFERENCE IMAGE
762
766
SET REFERENCE = NEXT IMAGE AFTER REFERENCE IMAGE IN OVERLAP LIST
YES
NO
CHECK IF REFERENCE IMAGE IS LAST IMAGE IN OVERLAP LIST?
764
YES
NO
CHECK IF BEST_CONFIDENCE > 0?
768
YES
TRANSLATE UNPOSITIONED IMAGE RELATIVE BEST_CONFIDENCE_IMAGE BASED ON THE OFFSET OF THE BEST_CONFIDENCE_IMAGE
770
APPEND IMAGES IN OVERLAP LIST AND THEIR OFFSETS TO THE ADJACENT LIST OF THE UNPOSITIONED IMAGE
772
ADD UNPOSITIONED IMAGE TO THE POSITIONED LIST
774
GO TO 704 (FIG 7A)

Fig. 7B

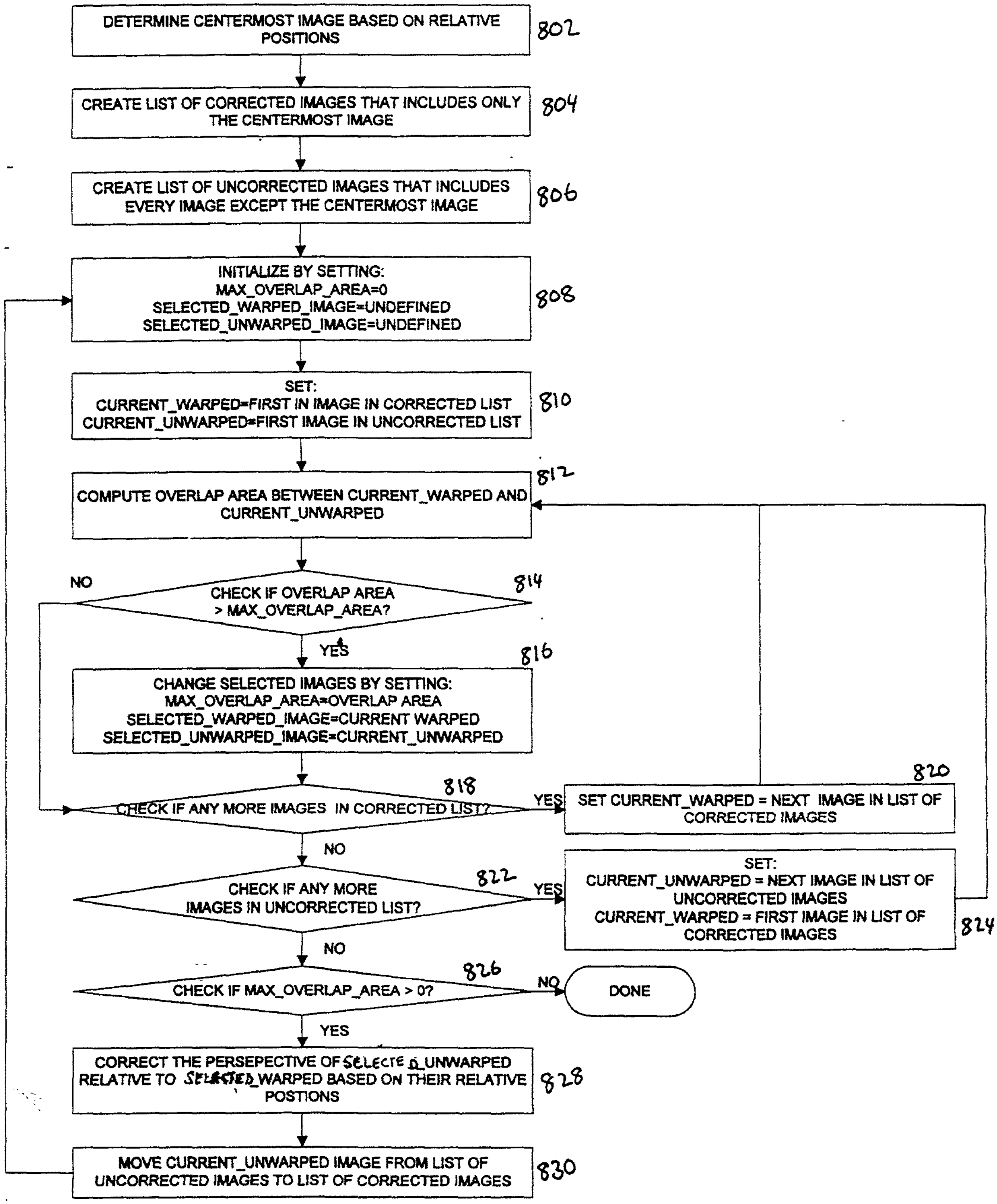

DETERMINE CENTERMOST IMAGE BASED ON RELATIVE POSITIONS
802
CREATE LIST OF CORRECTED IMAGES THAT INCLUDES ONLY THE CENTERMOST IMAGE
804
CREATE LIST OF UNCORRECTED IMAGES THAT INCLUDES EVERY IMAGE EXCEPT THE CENTERMOST IMAGE
806
INITIALIZE BY SETTING:
MAX_OVERLAP_AREA=0
SELECTED_WARPED_IMAGE=UNDEFINED
SELECTED_UNWARPED_IMAGE=UNDEFINED
808
SET:
CURRENT_WARPED=FIRST IN IMAGE IN CORRECTED LIST
CURRENT_UNWARPED=FIRST IMAGE IN UNCORRECTED LIST
810
COMPUTE OVERLAP AREA BETWEEN CURRENT_WARPED AND CURRENT_UNWARPED
812
CHECK IF OVERLAP AREA > MAX_OVERLAP_AREA?
814
NO
YES
CHANGE SELECTED IMAGES BY SETTING:
MAX_OVERLAP_AREA=OVERLAP AREA
SELECTED_WARPED_IMAGE=CURRENT WARPED
SELECTED_UNWARPED_IMAGE=CURRENT_UNWARPED
816
CHECK IF ANY MORE IMAGES IN CORRECTED LIST?
818
YES
SET CURRENT_WARPED = NEXT IMAGE IN LIST OF CORRECTED IMAGES
820
NO
CHECK IF ANY MORE IMAGES IN UNCORRECTED LIST?
822
YES
SET:
CURRENT_UNWARPED = NEXT IMAGE IN LIST OF UNCORRECTED IMAGES
CURRENT_WARPED = FIRST IMAGE IN LIST OF CORRECTED IMAGES
824
NO
CHECK IF MAX_OVERLAP_AREA > 0?
826
NO
DONE
YES
CORRECT THE PERSEPECTIVE OF SELECTED UNWARPED RELATIVE TO SELECTED WARPED BASED ON THEIR RELATIVE POSTIONS
828
MOVE CURRENT_UNWARPED IMAGE FROM LIST OF UNCORRECTED IMAGES TO LIST OF CORRECTED IMAGES
830

Fig. 8

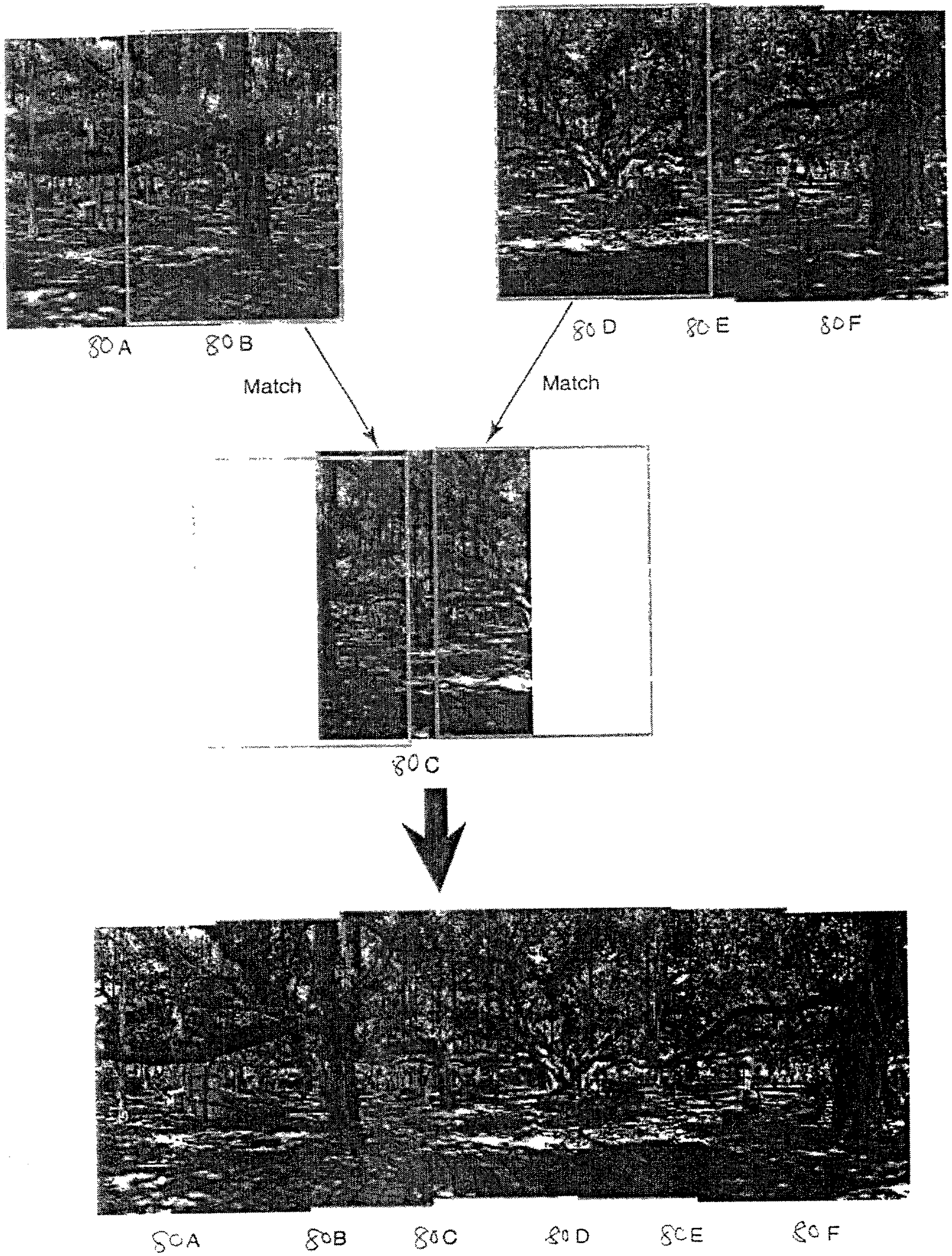


FIG.9

Original Image

	2-D coordinates	4-D coordinates
Vertex 0	(x_0, y_0)	$(x_0, y_0, 0, 1)$
Vertex 1	(x_1, y_1)	$(x_1, y_1, 0, 1)$
Vertex 2	(x_2, y_2)	$(x_2, y_2, 0, 1)$
Vertex 3	(x3, y3)	$(x_3, y_3, 0, 1)$
The i^th vertex	(x_i, y_i)	$(x_i, y_i, 0, 1)$

134

30

132

Fig. 10 A

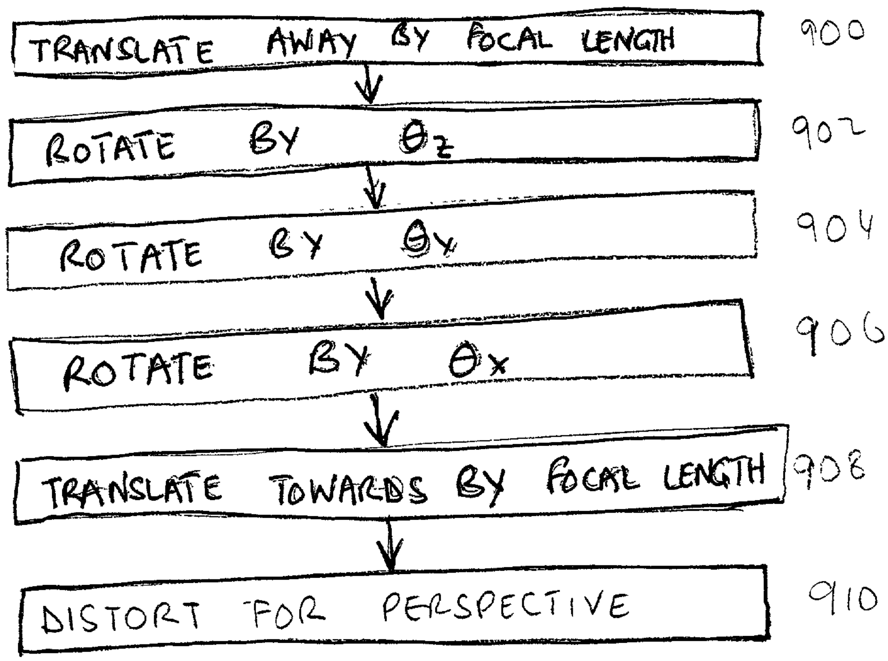


FIG. 10B

Perspective Correction Transformations

1. Translate outwards:

$$T_a = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & f & 1 \end{bmatrix}$$

136

2. Three rotations:

$$\Theta_x = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta_x & \sin\theta_x & 0 \\ 0 & -\sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

140

$$\Theta_y = \begin{bmatrix} \cos\theta_y & 0 & -\sin\theta_y & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta_y & 0 & \cos\theta_y & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

142

$$\Theta_z = \begin{bmatrix} \cos\theta_z & \sin\theta_z & 0 & 0 \\ -\sin\theta_z & \cos\theta_z & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

138

3. Translate inwards:

$$T_b = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -f & 1 \end{bmatrix}$$

144

4. Effect of focal length on Perspective:

$$P = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1/f \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

146

Fig. 10C

<u>Perspective Correction</u>

Perspective Corrected Image Vertices given by:

$$\hat{p}_i = p_i T_a \Theta_z \Theta_y \Theta_x T_b P = \underbrace{[\hat{x}_i, \hat{y}_i, \hat{z}_i, \hat{w}_i]}_{152} \qquad 150$$

But:

$$\hat{w}_i = -\frac{x_i}{f}(-\sin\theta_z \sin\theta_x + \cos\theta_z \sin\theta_y \cos\theta_y) + \frac{y_i}{f}(\cos\theta_z \sin\theta_x + \sin\theta_z \sin\theta_y \cos\theta_x) + \cos\theta_y \cos\theta_x$$

152

and x_i' and y_i' from the perspective corrected image are given by:

$$x_i' = \hat{x}_i / \hat{w}_i \quad \text{and} \quad y_i' = \hat{y}_i / \hat{w}_i$$

154 156

Therefore we can write:

$$F_{x_i}(\theta_z, \theta_y, \theta_x, f) - x_i' = 0 \qquad 158$$

Taking:

$$t = [\theta_x \quad \theta_y \quad \theta_z \quad f] \qquad 160$$

We can write:

$$\textbf{-F(t)} = \begin{bmatrix} x_o - F_{x_0}(\theta_z, \theta_y, \theta_x, f) \\ y_o - F_{y_0}(\theta_z, \theta_y, \theta_x, f) \\ . \\ . \\ x_i - F_{x_i}(\theta_z, \theta_y, \theta_x, f) \\ y_i - F_{yi}(\theta_z, \theta_y, \theta_x, f) \end{bmatrix} \qquad 162$$

Fig. 10D

Newton's Method

By Newton's method of numerical computation, **t** is an estimate of the values

$$\begin{bmatrix}\theta_x & \theta_y & \theta_z & f\end{bmatrix}$$

then:

$$t_{new} = t - J^{-1}F(t)$$ 166

is a better estimate of the values.

Where J^{-1} is the matrix of partial derivatives:

$$J_{i,j} = \frac{\partial F_i}{\partial t_j}$$ 164

Fig. 10E

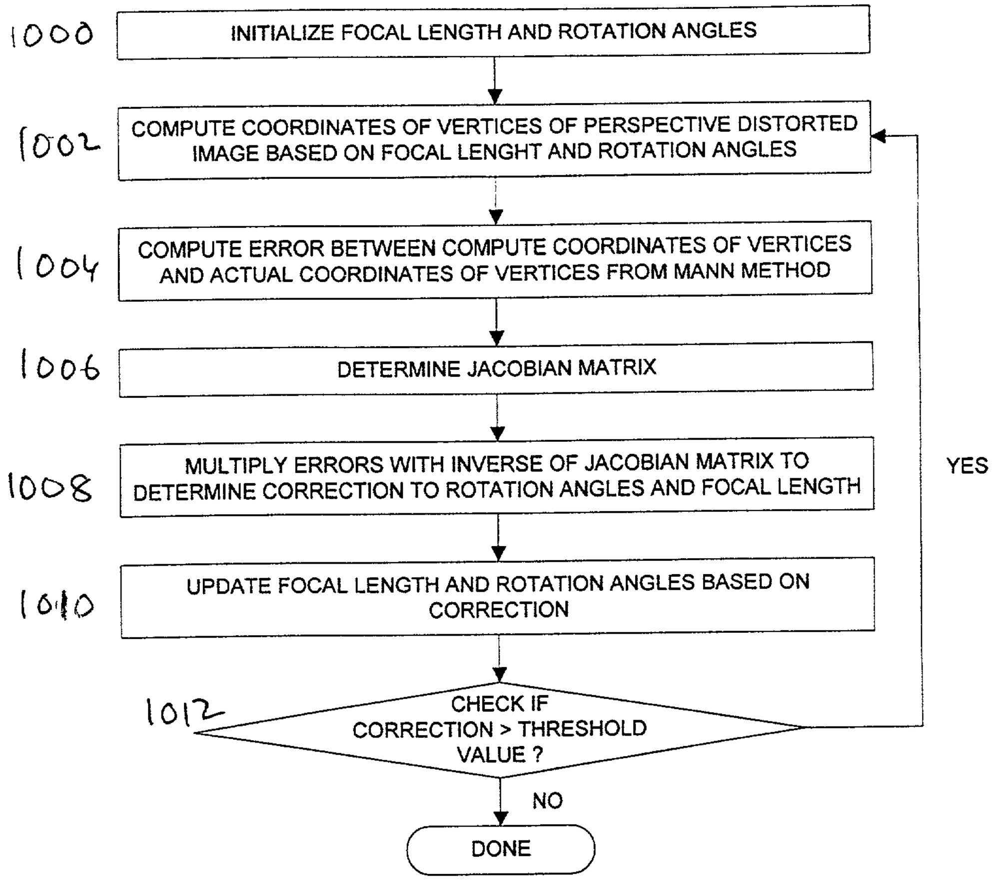

1000
INITIALIZE FOCAL LENGTH AND ROTATION ANGLES
1002
COMPUTE COORDINATES OF VERTICES OF PERSPECTIVE DISTORTED IMAGE BASED ON FOCAL LENGHT AND ROTATION ANGLES
1004
COMPUTE ERROR BETWEEN COMPUTE COORDINATES OF VERTICES AND ACTUAL COORDINATES OF VERTICES FROM MANN METHOD
1006
DETERMINE JACOBIAN MATRIX
1008
MULTIPLY ERRORS WITH INVERSE OF JACOBIAN MATRIX TO DETERMINE CORRECTION TO ROTATION ANGLES AND FOCAL LENGTH
1010
UPDATE FOCAL LENGTH AND ROTATION ANGLES BASED ON CORRECTION
1012
CHECK IF CORRECTION > THRESHOLD VALUE ?
YES
NO
DONE

Fig. 11

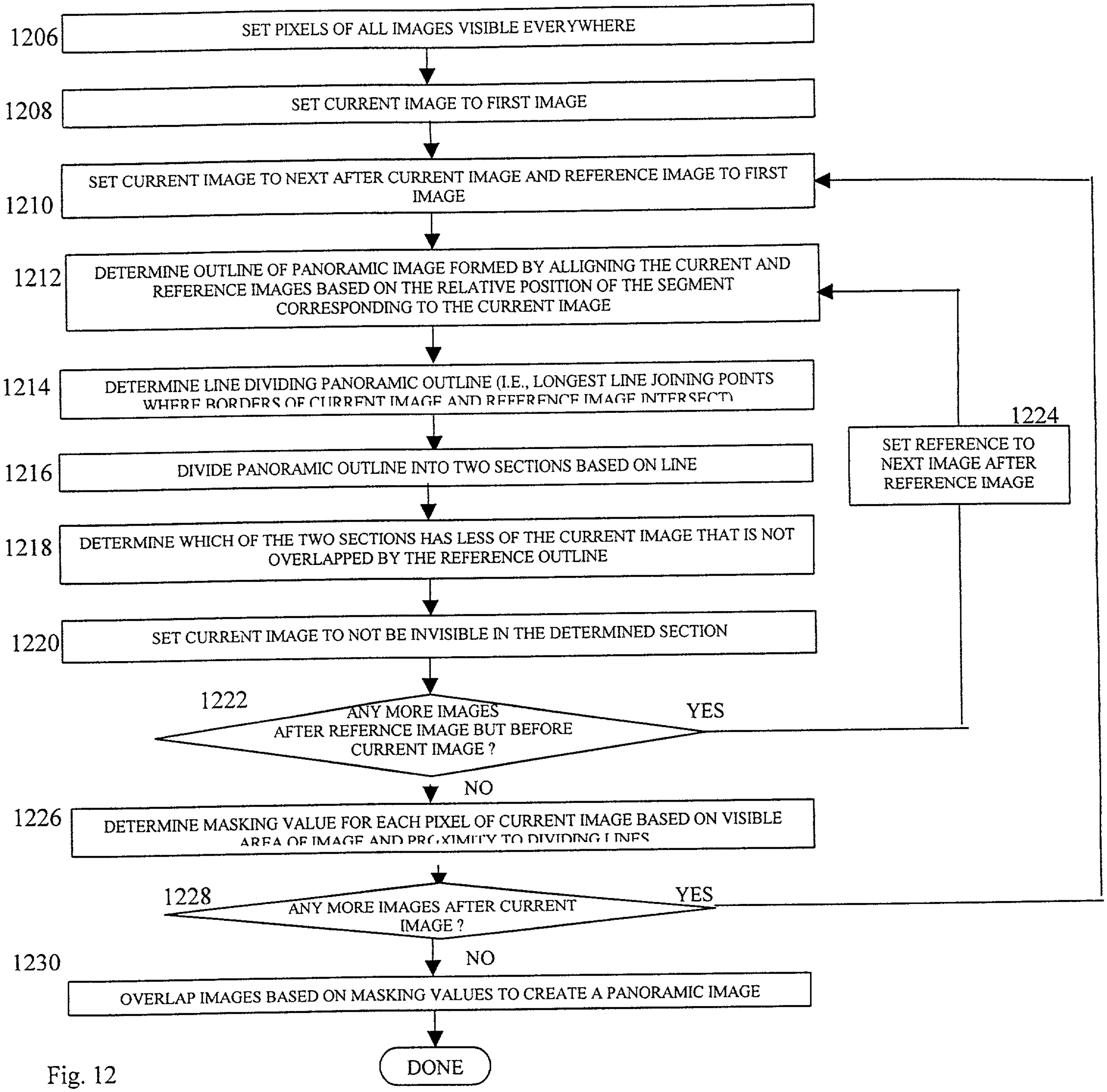

1206
SET PIXELS OF ALL IMAGES VISIBLE EVERYWHERE
1208
SET CURRENT IMAGE TO FIRST IMAGE
1210
SET CURRENT IMAGE TO NEXT AFTER CURRENT IMAGE AND REFERENCE IMAGE TO FIRST IMAGE
1212
DETERMINE OUTLINE OF PANORAMIC IMAGE FORMED BY ALLIGNING THE CURRENT AND REFERENCE IMAGES BASED ON THE RELATIVE POSITION OF THE SEGMENT CORRESPONDING TO THE CURRENT IMAGE
1214
DETERMINE LINE DIVIDING PANORAMIC OUTLINE (I.E., LONGEST LINE JOINING POINTS WHERE BORDERS OF CURRENT IMAGE AND REFERENCE IMAGE INTERSECT)
1216
DIVIDE PANORAMIC OUTLINE INTO TWO SECTIONS BASED ON LINE
1218
DETERMINE WHICH OF THE TWO SECTIONS HAS LESS OF THE CURRENT IMAGE THAT IS NOT OVERLAPPED BY THE REFERENCE OUTLINE
1220
SET CURRENT IMAGE TO NOT BE INVISIBLE IN THE DETERMINED SECTION
1222
ANY MORE IMAGES AFTER REFERNCE IMAGE BUT BEFORE CURRENT IMAGE ?
YES
1224
SET REFERENCE TO NEXT IMAGE AFTER REFERENCE IMAGE
NO
1226
DETERMINE MASKING VALUE FOR EACH PIXEL OF CURRENT IMAGE BASED ON VISIBLE AREA OF IMAGE AND PROXIMITY TO DIVIDING LINES
1228
ANY MORE IMAGES AFTER CURRENT IMAGE ?
YES
NO
1230
OVERLAP IMAGES BASED ON MASKING VALUES TO CREATE A PANORAMIC IMAGE
DONE

Fig. 12